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# Do Innovations Really Pay Off? Total Stock Market Returns to Innovation

Ashish Sood and Gerard J. Tellis

*Critics complain that firms do not invest in innovation because investments in innovation won't boost a firm's stock price. To the contrary, this study finds that stock markets respond promptly to announcements of innovation at all stages of the project.*

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## Report Summary

Critics often decry an earnings-focused short-term orientation of management that eschews spending on risky, long-term projects such as innovation in order to boost a firm's stock price. The critics assume that stock markets respond to announcements of earnings that report immediate earnings and not to announcements of innovations that have a long-term payoff. Contrary to this position, in the current study, Ashish Sood and Gerard Tellis argue that the stock markets react positively to innovation. However, the market's true appreciation of innovation can be estimated only by assessing the total market returns to the entire innovation project via event analysis. In the past, researchers computed market returns to only isolated innovation events, rather than the entire innovation project, as demonstrated in the current study.

The authors demonstrate this approach via the Fama-French Momentum four-factor model (FFM) on 5,481 announcements from 69 firms in 5 categories and 19 technologies, during the period 1977–2006.

Markets do respond promptly and substantially to announcements about innovation at all stages of the innovation project. For the innovation initiatives they study, total market returns to an innovation project are, on average, $643 million—more than 13 times the $49 million that has typically been found to accrue to an average innovation event.

In addition, the absolute value of a negative announcement is greater than that of a positive announcement. Thus, firms should be cautious not to exaggerate progress in their innovation projects or to resort to vaporware.

The authors divide innovation projects into three types of activity: setup, development, and market activities. Of these, returns to development activities are higher than returns to either setup or market activities. Thus, it is important that firms exploit progress in development by fully announcing all development-related events.

Their findings on various announcement strategies indicate that a mere increase or decrease in either the frequency or total number of announcements does not lead to an increase or decrease in returns. Moreover, the first announcement of a project is no more important than later announcements. ■

## Introduction

Innovation is probably one of the most important forces in fueling the growth of new products, sustaining incumbents, creating new markets, transforming industries, and promoting the global competitiveness of nations. Even so, many researchers, analysts, and managers fear that firms do not invest enough in innovation. According to the MIT *Technology Review*'s annual survey of R&D (Rotman 2004), corporate R&D spending across a broad cross-section of industries is on the decline. Some go so far as to complain that the United States may be losing its competitive edge and its famed leadership in innovation because of declining investment in research and development relative to other nations (Council on Competitiveness 2004a, b; Hall 1993). Firms may under-invest in R&D because of the high costs, the long delay in reaping market returns, if any, the uncertainty of those returns, and the difficulty of adequately measuring them. The increasing speed of diffusion across global markets (Chandrasekaran and Tellis 2008) and the diverse patterns of consumer adoption across products and countries (Sood, James, and Tellis 2008) further exacerbate the challenges for firms to predict returns to new products. Moreover, some critics assert that an earnings-focused, short-term orientation toward boosting stock price may undercut investments in innovation that typically have a long payoff. Such critics assume that the market does not reward efforts in innovation because returns to those efforts typically are evident only over the long term. Accurately assessing the market returns to innovation may be critical to understanding how markets respond to innovation and to motivating firms to invest in innovation.

The measure of abnormal stock market returns to innovation is one of the best means of assessing the true rewards to innovation. Past research has examined the effect of innovation on such firm performance measures as sales, profits, and market share. But these measures are subject to many other strategic and environmental factors, so that the path of causality is not clear. Under the assumption that the stock market is efficient, such returns can be assessed by an event study (Fama 1998). An event study measures the abnormal stock market returns to new information pertaining to an event, which are assumed to be proportional to the net present value of the new information. In an early application of this method, Chaney, Devinney, and Winer (1991) reported market returns of .25% to an isolated event—new product introduction. Past research has estimated returns to other isolated events relating to an innovation project (see Table 1).

This approach has three limitations. First, returns on specific events such as the launch of a new product do not reveal the total returns to innovation, which is really the sum of all events in an innovation project. A focus on returns to specific events in the innovation project may be one reason why markets appear to undervalue innovation. Second, a focus on specific events cannot reveal how returns are distributed over the entire project. Such knowledge is useful to understand which event of an innovation project gets the most returns and what announcement strategy firms should adopt. Third, returns on specific events may be deflated by excessive announcements or inflated by a paucity of announcements during the innovation project. We can ascertain this effect only by recording all announcements of all firms throughout the innovation project and estimating returns to an event after controlling for other events and strategic and structural variables.

Hence, a researcher may arrive at erroneous estimates of the true rewards to innovation by limiting the scope of study to announcements of only a new product's introduction or any other single event. As far as we know, there is no study of market returns to all events in an innovation project. This is the goal of the cur-

Table 1
### Events During Setup, Development, and Market Activities of Innovation Projects

| Phase | Setup | Development | Market |
|---|---|---|---|
| Events unique to this study | Funding (grants, advanced order, funded contracts)<br><br>Expansion (new development or manufacturing facilities) | Prototypes (development of working prototypes; identification of new materials, processes, or equipment; demonstration in exhibitions) | New product commercialization (shipments, new applications) |
| | This research (positive and negative events are recorded separately for announcements of all activities) | | |
| Events covered by prior research | Alliances (joint ventures, acquisitions) | Patents<br><br>Preannouncements (more than 1 week ahead of future events) | New product commercialization (launches)<br><br>Awards (external recognition of quality) |
| Prior research | Hirschey 1982<br>Jaffe 1986<br>Cockburn and Griliches 1988<br>Chan, Kensinger, and Martin 1992<br>Doukas and Switzer 1992<br>Hall 1993<br>Das, Sen, and Sengupta 1998<br>Chan, Lakonishok, and Sougiannis 2001<br>Suárez 2002 | Pakes 1985<br>Jaffe 1986<br>Erickson and Jacobson 1992<br>Kelm, Narayanan, and Pinches 1995 | Eddy and Saunders 1980<br>Woolridge and Snow 1990<br>Chaney, Devinney, and Winer 1991<br>Hendricks and Singhal 1996<br>Zantout and Chaganti 1996<br>Koku, Jagpal, and Viswanath 1997<br>Przasnyski and Tai 1999<br>Nicolau and Sellers 2002<br>Bayus, Erickson, and Jacobson 2003<br>Sorescu, Chandy, and Prabhu 2003<br>Pauwels et al. 2004<br>Sorescu, Shankar, and Kushwaha 2007<br>Tellis and Johnson 2007 |

rent study. In particular, we seek answers to the following questions:

- How do stock markets react to each event in an innovation project, after controlling for other events?
- What are the total market returns to the innovation project?
- What are the market returns to sets of activities of the innovation project?
- What structural (e.g., size) and strategic (e.g., research productivity) variables affect market returns to innovation?
- How do the market returns of competitors compare to those of the announcing firm?

The rest of the paper is organized as follows: The next three sections present theory, method, and findings. The last section discusses the findings, limitations, and implications of the research.

## Conceptual Background

This section reviews prior findings and expectations about market returns to innovation. To better lay out the area, it begins by defining the key terms and assumptions of the study.

### Definitions

We define four key terms: technology, innovation project, event, and announcement. Following Sood and Tellis (2005), we define a technology as a distinct principle or platform for producing products to serve a consumer need. For example, neon lamps are based on fluorescence technology which produces light by the distinct scientific principle of fluorescence. Halogen lamps are based on incandescence technology which produces light by the distinct scientific principle of incandescence (for details, see Appendix A). Several new products and models (e.g., hard disks, floppy drives, cassette tapes, etc.) may be developed on the platform of one technology (in this case, magnetic storage).

We define an innovation project as the total of a firm's activities in researching, developing, and introducing any new product based on a new technology, from the initiation of the technology to about a year after introduction of the new product(s). For example, all of Philips's research efforts in initiating, developing, and commercializing a compact fluorescent lamp (a new product based on fluorescence technology) comprises the innovation project for that new product.

We define an event as some progress in the project (e.g., patents or product launch). We identify seven such events, detailed in later sections.

We define an announcement as the availability of information regarding an event either by the firm directly or by other sources.

### Market returns to innovation events, activities, and projects

We identify three distinct sets of activities in the innovation project: setup, development, and market activities. Each set of activities includes key events related to the overall set that may occur any time during the innovation project. For example, firms may decide to enter into new alliances (a setup event) at any time during the innovation project. An event may be either positive (for example, a patent registration) or negative (a patent denial) (see Appendix B for details). Total market returns to the entire innovation project are the sum of returns to all the events associated with all the activities during the innovation project. At the present state of research, the literature reports rival findings about whether returns to these events are negative or positive, as summarized below.

Setup activities include events relating to alliances (including joint ventures and acquisitions), funding (including grants, advanced orders, and funded contracts), and expansions for the start of new innovation projects. Announcements about setup activities may lead to negative returns because of high investments, long gestation periods, uncertainty, and high risk of failure associated with innovation projects (Crawford 1977; Kelm, Narayanan, and Pinches 1995). On the other hand, such announcements may lead to positive returns as they enable market expansion, deter competitor entry, improve probability of success, and enhance firms' competitive position (Aaker 1995; Anand and Khanna 2000; Das, Sen, and Sengupta 1998; Doukas and Switzer 1992; Suárez 2002). The rival arguments for positive and negative market returns to setup activities suggest the need for empirical research to resolve the conflict.

Development activities include events relating to prototypes (creation of working prototypes, demonstration in exhibitions, and identification of new materials, equipment, and processes), patents, and preannouncements

(announcements made more than a week ahead of future events). Announcements about development activities may lead to negative returns because they may alert competitors of progress, reduce the element of surprise, trigger imitators, or lead to excessive discounting of the technical content. On the other hand, returns to development activities may be positive due to reduction in overall uncertainty, signaling confidence, competence, and optimism about the future (Austin 1993; Pakes 1985; Paulson Gjerde, Slotnick, and Sobel 2002; Sorescu, Shankar, and Kushwaha 2007; Zantout and Chaganti 1996). The rival arguments for positive and negative market returns to development activities suggest the need for empirical research to resolve the conflict.

Market activities include events relating to new product commercialization (including launches, initial shipments, and new applications) and awards (external recognition of quality). Announcements about market activities may lead to negative returns because launched products fall below expectations, costs of promotion and commercialization seem high, or the competitive advantages from commercialization seem fleeting (Berenson and Mohr-Jackson 1994; Crawford 1977). On the other hand, announcements of market activities may lead to positive returns because they signal the competitiveness of the firm, the successful completion of innovation projects, and the expansion of the product portfolio (Akhigbe 2002; Chan, Kensinger, and Martin 1992; Chaney, Devinney, and Winer 1991; Chen, Ho, and Ik 2005; Hendricks and Singhal 1996; Johnson and Tellis 2007; Sankaranarayanan 2007; Sharma and Lacey 2004; Urban and Hauser 1980; Zantout and Chaganti 1996). The rival arguments for positive and negative market returns to market activities suggest the need for empirical research to resolve the conflict.

### Total returns to innovation

Past research has estimated returns to isolated events of an innovation project (see Table 1). This approach may lead to a substantial underestimation of the total returns to innovation. We propose that the total returns to innovation can be estimated only if all events in all sets of activities that comprise the innovation project are included in the analysis. If the returns to the entire innovation project could be estimated from a single, target event during the project, then returns for other events would not be significantly different from zero. That target event would be critical, with important implications for firms and investors. On the other hand, if firms continue to experience incremental returns to various events over the innovation project, ignoring certain events would result in underestimating the total returns to innovation. It would also mean that firms (and investors) should be paying close attention to all innovation-related events so as to optimize their announcement strategy (or their investment strategy). The total returns to innovation are the sum of returns to all events in an innovation project. Similarly, if a firm has multiple innovation projects running concurrently, the total returns to innovation to the firm are the total return to all innovation projects of the firm.

In addition to completeness, the benefit of considering all events in an innovation project is that it compensates for suboptimal or strategic announcements of the firm. For example, if the firm under-promises in the early stages of an innovation project and over-delivers in later stages, the possibly too-low market returns in the early stages will be compensated by high returns in later stages. Conversely, if a firm over-promises and then under-delivers, taking all events into consideration will compensate for the possibly too-high returns in earlier stages.

### Activities with the highest returns

Researchers and managers may want to know which activities attract the highest returns. We are not aware of any specific study that examines this question or any specific theory that concludes that one particular set of activities elicits better returns than others. However, past research seems to suggest that announcements of market activities may experience the highest returns for several reasons. First, only market activities generate revenues from sales of the new product (Chan, Kensinger, and Martin 1992; Sharma and Lacey 2004). Second, based on research to date, market activities get the most attention from the media.

### Control variables

Market returns during the innovation project may also be affected by the firm's announcement strategy or structure. For this reason, our control variables include two strategic variables (announcement frequency and research productivity) and two structural variables (size of firm and age of technology). The rationale for including each of these control variables follows.

**Announcement Frequency.** Firms vary in their announcement strategies. Some firms, like Microsoft, announce all events related to the project, while others, like Apple, aggregate many events into one big announcement. Some literature suggests that frequent announcements reflect transparency and timeliness and thus should either enhance returns or at least not lead to penalty in returns (Givoly and Palmon 1982; Kelm, Narayanan, and Pinches 1995; Tucker 2007). However, frequent and multiple announcements lead to dilution of returns over a larger number of events and thus lower realized returns per announcement (Chaney, Devinney, and Winer 1991). We use two alternate measures for announcement frequency: number of prior announcements and days since last announcement. We expect returns to be negatively correlated to the first measure and positively correlated to the second measure.

**Research Productivity.** A high level of research productivity may increase returns for a couple of reasons. First, a high level of research productivity may signal to customers that the firm is innovative, and customers may perceive an innovative firm as having superior products and thus drive up demand for its new innovations (Barney 1986; John, Weiss, and Dutta 1999). Second, a firm with a reputation for a regular stream of innovative products may have an increased ability to make fruitful strategic alliances (Dollinger, Golden, and Saxton 1997), which could increase the probability of success with the current innovation. Hence, market returns may be high to firms with high research productivity. We measure research productivity by the number of new product launches per year prior to the date of the current event.

**Size of Firm.** Prior research suggests that a firm's size is an important structural variable that affects the market returns to innovation: returns for smaller firms are higher than returns for larger firms because any single event has higher salience in a small firm than it does in a large firm (Austin 1993). Large firms are also better tracked by analysts, and in general their event returns offer much smaller "surprises." Our two measures of firm size are annual sales and the number of different technologies in which a firm invests.

**Age of Technology.** Market returns to innovation projects may differ across old and new technologies. Prior research suggests that technologies mature with time (Chandy and Tellis 2000; Christensen 1992; Foster 1986) and that the focus of innovation changes from product to process innovation as a technology matures (Adner and Levinthal 2001; Utterback 1974). Hence, there may be fewer improvements in product performance for older technologies. In contrast, new technologies improve rapidly, open up new opportunities and markets, and can disrupt old technologies (Christensen 1997). Thus, market returns to new technologies may be higher than those to old technologies. We measure age of technology by the number of years that have passed since the launch of the first new product based on the technology.

## Method

This section describes the method for estimating abnormal returns to announcements during the innovation project in five subsections: logic of the event study, model for data analysis, and sample, sources, and procedure for the data collection.

### Logic of event study

The event study (Fama et al. 1969) is one of the most widely used analytical tools in financial research. The basic assumption underlying the method is the efficient market hypothesis, which states that a stock price at a particular point in time fully reflects all available information up to that point (Fama 1998; Sharpe 1964). Thus, any change in the price of a stock due to the arrival of new information reflects the present value of all expected current and future profits from that new information. The method has been widely used in the finance, accounting, economics, management, and marketing literatures to assess the market value of information contained in various events of interest. The market returns to an event of a firm is the change in the stock price of that firm due to that event, above that due to the general market at the time of the event.

### Model

We estimate abnormal returns to the event using the Fama-French three-factor model (Fama and French 1993) and including Carhart's momentum factor (Carhart 1997). Prior studies in event studies have relied on the standard capital asset pricing model, which assumes that the market portfolio is the benchmark for normal returns to a stock (McKinlay 1997). The Fama-French three-factor model expands on the capital asset pricing model by adding two more factors: market capitalization and value. More recently, Carhart proposed the addition of a fourth factor, price momentum, to account for persistence effects in returns reported by Jegadeesh and Titman (1993). Thus, the combined Fama-French Momentum four-factor model (FFM) is:

$$R_{it} - R_{ft} = \alpha_i + \beta_{1i}(R_{mt} - R_{ft}) + \beta_{2i} SMB_t + \beta_{3i} HML_i + \beta_{4i} UMD_i + \varepsilon_{it} \quad (1)$$

$$E[\varepsilon_{it}] = 0; \; Var[\varepsilon_{it}] = \sigma^2_{\varepsilon_i}$$

where

$t$ is a subscript for time of the estimation window, such that $-270 \leq t \leq -6$

$i$ is a subscript for announcement

$R_i$ = returns on announcement $i$ on day $t$

$R_m$ = returns on corresponding daily equally weighted S&P 500

$R_f$ = theoretical rate of return attributed to an investment with zero risk

*SMB* = returns on a portfolio of small stocks minus returns on large stocks

*HML* = returns on a portfolio of stocks with a high book-to-market ratio minus the returns on a portfolio of stocks with a low book-to-market ratio

*UMD* = Carhart's price momentum factor, which captures a year's momentum in returns

$\varepsilon_{it}$ is the disturbance term. $\alpha_i$, $\beta_{1i}$, $\beta_{2i}$, $\beta_{3i}$, $\beta_{4i}$, and $\sigma^2$ are the parameters of the model to be estimated. The risk-free rate represents the interest that one expects from a risk-free investment over a specified period of time. The interest rate on a three-month U.S. Treasury bill is commonly used as a proxy for the risk-free rate because short-term government-issued securities have virtually zero risk of default.

The returns variables are also computed at the level of project, $p$. We have suppressed subscripts for this level in the first four equations for ease of reading.

We estimate the parameters of Equation 1 using an estimation period from 270 to 6 days prior to the announcement. For some new firms that were listed on the stock exchange for a short period before the announcements, we use a shorter estimation period. However, we remove any announcement with an estimation period of less than 30 days.

We next compute abnormal returns ($AR_{it}$) to an event as the difference between the normal returns which would have occurred on that day given no event and the actual returns that did occur because of the event, thus:

$$AR_{it} = R_{it} - E[R_{it}] = R_{it} - R_{ft} - \left[(\hat{\alpha}_i + \hat{\beta}_{1i}(R_{mt} - R_{ft}) + \hat{\beta}_{2i}SMB_t + \hat{\beta}_{3i}HML_t + \hat{\beta}_{4i}UMD_t\right] \quad \text{for } -1 \leq t \leq 1 \tag{2}$$

where $AR_{it}$, $R_{it}$, and $E(R_{it})$ are the abnormal, observed, and normal returns respectively for announcement $i$ and event window $t$. We also try windows of varying widths centered on the date of announcement, ±1 and ±2 days before and after the event.

We estimate average abnormal returns and the $t$-statistic θ (Brown and Warner 1985) for the portfolio of $N$ announcements of an event thus:

$$AAR_t = \frac{1}{N}\sum_{i=1}^{N} AR_{it} \tag{3}$$

$$\theta = \frac{AAR_t}{SD(AAR_t)} = \frac{AAR_t}{\sqrt{\frac{1}{(T_0 - 1)} \sum_{t=1}^{t=T_0} (AAR_t - \overline{\overline{AAR}})^2}} \tag{4}$$

where $AAR_t$ is the average (abnormal) returns for an event and $T_0$ is the number of days in the estimation window, which in our case is 270 – 5 = 265, and

$$\overline{\overline{AAR}} = \frac{1}{T_0}\sum_{t=1}^{T_0} AAR_t \,.$$

Note that this portfolio $t$-test statistic explicitly takes into account any potential cross-sectional dependence in the abnormal returns.

We compute cumulative average abnormal returns ($CAR_i$) in the event window as follows:

$$CAR_i = \sum_{t=t_1}^{t=t_2} AR_{it} \tag{5}$$

where $t_1$ and $t_2$ denote the beginning and end of the event window.

We also estimate the cumulative average abnormal returns (CAAR) using alternative models which are explained in the results section. We estimate the following model to ascertain the effect of hypothesized independent variables on cumulative abnormal returns ($CAR_{ijp}$) thus:

$$CAR_{ijp} = \alpha + \beta_1 AL_{ijp} + \beta_2 FN_{ijp} + \beta_3 EP_{ijp} + \beta_4 PR_{ijp} + \beta_5 PT_{ijp} + \beta_6 PA_{ijp} + \beta_7 PL_{ijp} + \beta_7 RQ_{ijp} + \beta_8 AF_j + \beta_9 SZ_j + \beta_{10} RP_j + \beta_{11} AT_p + \eta_{ijp} \tag{6}$$

where
$AL_{ijp}$ = announcements of alliances
$FN_{ijp}$ = announcements of funding
$EP_{ijp}$ = announcements of expansion
$PR_{ijp}$ = announcements of prototypes
$PT_{ijp}$ = announcements of patents
$PA_{ijp}$ = preannouncements
$PL_{ijp}$ = announcements of commercialization
$RQ_{ijp}$ = announcements of awards
$AF_{jp}$ = announcement frequency
$SZ_j$ = size of firm
$RP_j$ = research productivity of the firm
$AT_p$ = age of technology
and subscripts refer to announcement $i$, firm $j$, and project $p$, respectively.

## Sample

We collect data using the historical method (Golder 2000; Golder and Tellis 1993) on 19 technologies in five categories—external lighting, display monitors, computer memory, data transfer technologies, and desktop printers (Appendix A). We use the term category interchangeably to refer to product categories, markets, or industries in line with prior research using historical method (Golder and Tellis 1993). We use two criteria in selecting categories: a reasonable number of emerging technologies and data availability. We select

Table 2
Sample Characteristics

| Category | External lighting | Display monitors | Desktop memory | Data transfer | Printers |
|---|---|---|---|---|---|
| Number of firms | 19 | 17 | 18 | 17 | 11 |
| Total number of announcements | 696 | 1,100 | 1,239 | 1,323 | 1,123 |
| Sample period | 1977–2006 | 1980–2006 | 1979–2006 | 1982–2006 | 1981–2006 |
| Setup activities | 155 | 278 | 270 | 327 | 117 |
| Development activities | 171 | 305 | 274 | 183 | 126 |
| Market activities | 370 | 517 | 695 | 813 | 880 |
| Number/type of platform technologies | 5 | 5 | 5 | 3 | 4 |
| | Incandescence, arc discharge, gas discharge, LED, MED | CRT, LCD, plasma, display panels, OLED | Magnetic, magneto-optical, optical | Copper/ aluminum, fiber optics, wireless | Dot matrix, inkjet, laser, thermal |

categories in which a number of technologies have emerged in the last few decades and the key global players are in U.S. markets. The first requirement is essential to ensure that we have a large sample of announcements and the second is essential since we require the firm to be listed on U.S. stock markets in order to assess the market value. We identify a total of 69 firms in the five categories and collect a total of 5,481 announcements from 1977 until 2006 (see Table 2). There is substantial innovative activity in all the categories during this period. While the number of announcements is approximately the same for setup and development activities, they increase sharply for market activities, probably because firms feel the need to inform the market about commercialization in order to boost sales.

The present study goes further than previous studies in two important aspects. First, we identify all major firms and all technologies within each category. Second, we collect all announcements related to innovation projects made by the firms for each activity of the project.

### Sources

Although many studies limit their focus to a single source of announcements, we posit that information on innovation projects reaches the markets through a variety of sources, so, limiting the source to only one publication would risk failing to capture the date when information is first released to the markets. Glascock, Davidson, and Henderson (1987) have shown, for example, that *The Wall Street Journal* does not publish all the news and that there is a lag of three days between changes in Moody's bond ratings and *Wall Street Journal* announcements of those changes. Hence, in the interests of accuracy and comprehensiveness, we include other sources of information as well. The primary sources we use are FACTIVA (which includes *The Wall Street Journal*), LexisNexis, and company websites. We also include all newswire services (e.g., PR Newswire, Business Newswire, and Reuters). We collect company background information from General Business File ASAP and Yahoo Finance.

### Procedure

After selection of the category, we identify all major firms in the category and collect information on each firm. We use the following key words to identify all the announcements: name or ticker symbol of firm, names of technology, and events connected to the innovation project. We sort the results based on oldest press

Table 3

Descriptive Statistics–Abnormal Returns to an Average Event by Category for Various Windows

| | | AAR (Event Day) | | | | | CAAR (±1 days) | | CAAR (±2 days) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Category | *N* | Est. (%) | *t*-value | *p*-value[1] | % Positive | *p*-value[2] | Est. (%) | *t*-value | Est. (%) | *t*-value |
| All | 5,481 | .4 | 7.4 | < .0001 | 52 | < .0001 | .5 | 14.7 | .5 | 3.3 |
| Lighting | 696 | .9 | 6.3 | < .0001 | 56 | < .0001 | 1.1 | 13.7 | 1.4 | 3.6 |
| Monitors | 1,100 | .8 | 3.5 | < .0001 | 51 | .015 | .7 | 5.7 | .4 | .7 |
| Memory | 1,239 | .3 | 2.7 | .0135 | 51 | .004 | .5 | 9.3 | .4 | 1.4 |
| Data Transfer | 1,323 | .2 | 2.8 | .0047 | 51 | .004 | .2 | 4.6 | .3 | 1.5 |
| Printers | 1,123 | .1 | 1.8 | .1301 | 51 | .026 | .1 | 1.6 | .3 | 1.5 |

Note:
[1] The *p*-value is estimated using the Brown-Warner (1985) approach.
[2] The *p*-value is estimated by sorting the 265 average abnormal returns from minimum to maximum and calculating how far away from the tail in rank the event average abnormal return is for these 265 values. We thank an anonymous reviewer for suggesting this.

report first to identify the first release of information to the market. We exclude press reports appearing in non-daily publications because of inherent inaccuracy of determining the exact date of release of information. Of the remaining press reports, when multiple reports contain identical information about an event, we retain only the first press report, which we treat as the announcement. However, an event may have multiple announcements because of new information in each announcement. Finally, we include announcements in the analysis only for those firms whose data are available from CRSP (firms traded on NYSE, AMEX, or NASDAQ) because we need price information to estimate returns. We examine each announcement to classify the announcement by firm, by innovation project, by project activity, and by event within the activity.

## Results

Our analysis of the market response to innovation announcements using the event study method suggests that the cumulative average abnormal returns to all announcements in the sample are positive (see Table 3). Across all categories, the cumulative average abnormal returns to all announcements are .4% on the event day. This result holds even at the level of the individual category. Moreover, the returns are the highest on the day of the announcement and not significantly different from zero for event windows longer than 5 days (±2 days around the day of announcement) (see Table 3 and Figure 1). Hence, in the rest of the paper, we use the abnormal returns for an event window of only one day and use the term *returns* to mean abnormal returns. The returns that we report are for the FFM model (Equation 1), though we explore returns by other methods in a later subsection.

We present the results in four subsections: analysis of returns, analysis of total returns, additional analyses, and test of robustness.

### Analysis of returns by activity

We classify announcements as either positive or negative information based on their content. The number of negative announcements across all three sets of activities was approximately 5% of the number of positive announcements. We estimate the cross-sectional average return to each event in each set of activities using the univariate method (Equation 3) and the multivariate method, after controlling for various strategic and control variables (Equation 6).

Table 4

## Average Abnormal Returns to Various Events during Innovation Projects

| | Univariate (Equation 3) | | | | | | Multivariate (Equation 6) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Positive only | | | Negative only | | | Positive only | | Negative only | | All [2] | |
| Announcements | *N* | Est. (%) | *t*-value[1] | *N* | Est. (%) | *t*-value[1] | Est. (%) | *t*-value | Est. (%) | *t*-value | Est. (%) | *t*-value |
| Intercept | | | | | | | –.02 | –.1 | .6 | 4.6 | .2 | 1.0 |
| Alliances | 878 | .6 | 5.1 | 34 | –.02 | –.1 | .5 | 3.3 | .2 | .4 | .4 | 2.6 |
| Funding | 154 | .9 | 2.3 | 18 | –1.3 | –.6 | .7 | 2.1 | –1.1 | –1.4 | .4 | 2.4 |
| Expansion | 181 | .6 | 2.2 | 29 | –.6 | –.9 | .4 | 1.1 | –.3 | –.2 | .2 | .7 |
| Prototypes | 776 | 1.0 | 9.0 | 21 | –4.2 | –5.9 | .6 | 3.5 | –2.3 | –2.4 | .5 | 2.6 |
| Patents | 218 | 1.6 | 4.0 | 85 | –1.6 | –2.5 | 1.4 | 4.9 | –1.8 | –4.4 | .4 | 1.6 |
| Preannouncements | 762 | 1.2 | 8.8 | 39 | –4.7 | –9.6 | .9 | 5.3 | –3.2 | –4.3 | .6 | 3.6 |
| Commercialization | 2,106 | .2 | 2.5 | 16 | –4.7 | –7.2 | .2 | 1.6 | –2.2 | –2.2 | .01 | .1 |
| Awards | 488 | 1.2 | 5.2 | | | | .8 | 3.9 | .0 | 1.8 | .7 | 3.0 |
| Announcement frequency[3] | | | | | | | 1.8E–05 | 1.0 | –7.9E–08 | –3.9 | 2.4E-05 | 1.4 |
| Size of firm[4] | | | | | | | –8.6E–08 | –4.2 | –8.0E–05 | –1.07 | –8.2E–08 | –4.0 |
| Research productivity | | | | | | | –5.8E–05 | –.8 | 1.3E–05 | .4 | –5.7E–05 | –.8 |
| Age of technology | | | | | | | 3.4E–05 | 1.1 | 1.3E–05 | .4 | 2.6E–05 | .8 |
| Adj. $R^2$ | | | | | | | 2.48 | | 2.24 | | 1.48 | |

Note:
[1] Estimated using Brown-Warner (1985) method (Equation 4).
[2] Announcement frequency was measured by the number of prior announcements.
[3] Positive announcements coded as 1 and negative announcements coded as –1.
[4] Size of firm was also measured by the number of different technologies in which a firm invests.

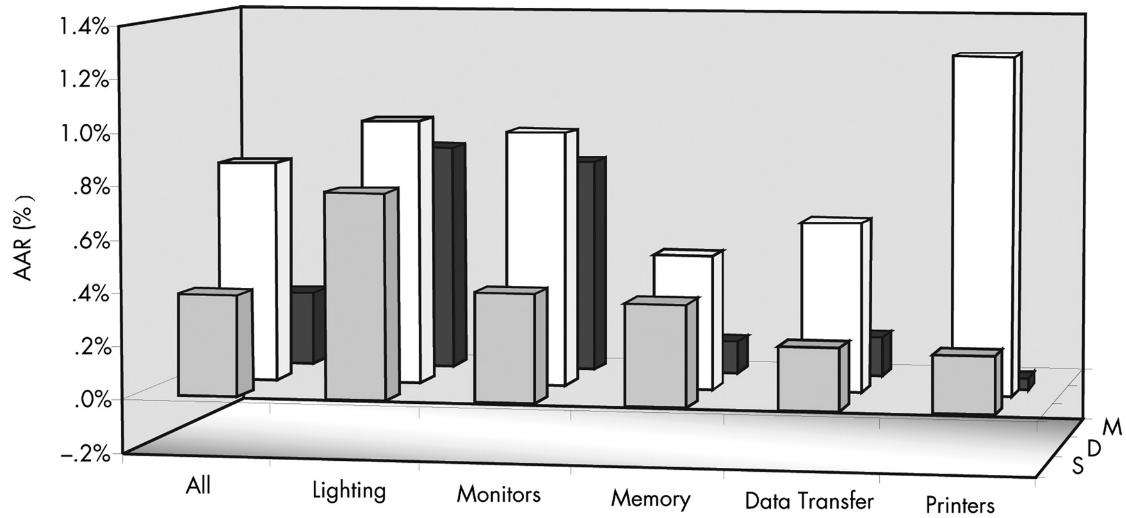
The results are consistent with each other, and returns to most of the set of activities and events are significantly different from 0 (see Table 4). Initial examination of the data suggests heteroscedasticity, so we use Proc GLM in SAS. Table 4 reports these consistent estimates (refer to the section on regression diagnostics, below, for more details). The adjusted $R^2$ for the models is at least 2.2%, which is comparable to prior studies (Chaney, Devinney, and Winer 1991; Koku, Jagpal, and Viswanath 1997; Sorescu, Shankar, and Kushwaha 2007).

**Setup Activities.** Across all categories, the returns to all setup activities are .6% ($t$ = 3.7). The findings indicate that firms gain by announcing their setup activities. At the event level, market returns are high for positive announcements of alliances (.6%, $t$ = 5.5), funding (.9%, $t$ = 2.3), and expansion plans (.6%, $t$ = 2.2) (see Table 4). On the other hand, the returns were not significantly different from zero for the negative announcements of either breakup or termination of alliances (–.3%, $t$ = –.9), decrease or delay in funding to projects (–1.3%, $t$ = –.6), or expansion plans (–.6%, $t$ = –.9). A possible reason for these results is that while firms may keep information on forthcoming joint ventures under wraps, investors have other indicators of equivalent forthcoming negative events, such as the dissolution of an existing joint venture, before the actual formal announcement, so that when the actual negative event is announced, its impact is not that bad.

**Development Activities.** Across all categories, the returns to all development activities are .9% ($t$ = 5.5). At the event level, market

Figure 1

### Average Abnormal Returns (AAR) in Each Set of Activities of Innovation Project




| | All | Lighting | Monitors | Memory | Data Transfer | Printers |
|---|---|---|---|---|---|---|
| S | .4% | .8% | .4% | .4% | .2% | .2% |
| D | .8% | 1.0% | 1.0% | .5% | .6% | 1.3% |
| M | .3% | .9% | .8% | .1% | .2% | .0% |

returns are strongly positive for announcements of successful demonstrations of prototypes (1.0%, $t$ = 9.0), patents (1.6%, $t$ = 4.0), and preannouncements (1.2%, $t$ = 8.8) (see Table 4). A majority of the positive announcements relating to patents are announcements of awards of patents. Surprisingly, negative returns for negative announcements are even higher in absolute value than the positive returns. For example, returns are –4.2% ($t$ = –5.9) for announcements of delays in meeting product development deadlines or failure to meet expected performance levels, –1.6% ($t$ = –2.5) for denial of patents or patent infringement suits, and –4.7 ($t$ = –9.6) for postponement, delay, deferral, shelving, or suspension of projects.

**Market Activities.** Across all categories, the returns to all market activities are .3% ($t$ = 2.5). At the event level, market returns are positive for announcements of the launch of new products (.2%, $t$ = 2.5) and receipts of awards (1.2%, $t$ = 5.2) (see Table 4). In contrast, market returns to delays in product launches, cancellation of plans to launch products, and product recalls due to malfunctions have a negative return of –4.7% ($t$ = –7.2).

In summary, we find that market returns to negative announcements are negative across all events, and the absolute value of the market returns is higher for negative announcements than for positive announcements. This result is consistent with the theory and empirical findings that losses loom larger than gains (Kahneman and Tversky 1979).

### Activities with the highest returns

We find that the highest returns are for development activities (see Figure 1). The difference in returns to development activities and returns to setup activities is significantly greater than zero ($t$ = 2.7). Similarly, the returns are greater than returns to market activities ($t$ = 4.0). At the individual category level, the returns to development are more than the returns to market activities or setup activities in all five categories.

Table 5

### Total Abnormal Returns to Innovation by Category

| Stage | Total Abnormal Returns (%) (Equation 7) | Total Abnormal Returns ($M) (Equation 9) |
|---|---|---|
| All | 10.3 | 972 |
| Lighting | 13.1 | 712 |
| Monitors | 19.8 | 1,275 |
| Memory | 7.02 | 446 |
| Data transfer | 7.4 | 2,635 |
| Printers | 3.8 | 432 |

### Results for strategic and structural variables

The results of the analysis of strategic and structural variables estimated via the model in Equation 6 (see Table 4) are the following:

- A higher (or lower) number of prior announcements or longer time since last announcement within a project does not lead to higher returns. The results remain similar even if we code the prior number of positive or negative announcements separately.
- Although returns are highest for development activities, market activities garner the highest number of announcements.
- Returns are higher for smaller firms than for larger firms.
- The age of technology does not have an effect on the market returns to innovation.
- Firms with higher research productivity (across projects) do not have higher returns per announcement than firms with lower research productivity. When we use an alternative measure of research productivity—the number of different technologies in which a firm invests—we find that returns for firms that invest in a small number of technologies are higher than returns for firms that invest across a broad set of technologies ($t = -3.2$).

### Analysis of total returns

The total returns to an innovation project can be calculated as the sum of returns to all events within that innovation project. We exclude firms where data on shares outstanding are not available from CRSP. We then calculate the returns to each project as the sum of returns to all announcements for that project:

$$TR_{jp} = RAL_{jp} + RFN_{jp} + REP_{jp} + RPR_{jp} + RPT_{jp} + RPA_{jp} + RPL_{jp} + RRQ_{jp} \quad (7)$$

where $TR_{jp}$ is total returns to firm $j$ for project $p$, and $RAL_{jp}$, $RFN_{jp}$, $REP_{jp}$, $RPR_{jp}$, $RPT_{jp}$, $RPA_{jp}$, $RPL_{jp}$, and $RRQ_{jp}$ are returns to all announcements of alliances, funding, expansion, prototypes, patents, preannouncements, commercialization, and awards for project $p$ respectively.

We estimate the average return to a project across the sample as

$$ATR_p = \frac{\sum TR_{jp}}{J} \quad (8)$$

where $J$ is the total number of projects in the sample. Table 5 shows that the total returns (averaged across all categories) are 10.3%. The total returns by category are about 13.1% for projects in lighting, 19.8% for projects in monitors, 7.02% for projects in memory products, 7.4% for projects in data transfer, and 3.8% for projects in printers. More importantly, the simple average return for any event is .6%, which is comparable to estimates of returns to innovation reported by prior studies. However, this value is substantially lower than the mean of 10.3% for the whole innovation project. Hence, ignoring the totality of events of innovation, when estimating returns, severely underestimates the total returns to innovation.

To estimate the dollar value of returns to projects, we first compute dollar returns to announcements:

$$CARD_{ijp} = CAR_{ijp} * SO_j * SP_j \quad (9)$$

where $CARD_{ijp}$ = returns in dollars for announcement $i$, $SO_j$ = number of shares outstanding for firm $j$ on day of announcement $i$, and $SP_j$ = price of shares for firm $j$ at the end of that trading day.

We then follow the procedure described above to compute the dollar value of returns to specific events, the average value of the return to an event for a project, and the value of the total return to the whole project. Across the five markets, the average return to an event is $49 million, while the average total return to any project is $643 million. Again, taken across or within categories, returns to projects are more than 13 times the returns to individual events.

## Additional analyses

We now present two additional analyses: returns to first announcements relative to later announcements and returns relative to competitors.

**First Announcement.** Readers may suspect that the first announcement of an innovation project would yield higher returns than any other announcement. The reason may be that the first announcement tells of a whole new project or product by the firm. Subsequent announcements may not have as big an informational or signaling impact (Klein and Leffler 1981; Le Nagard-Assayag and Manceau 2001). We test this hypothesis. We define the first announcement as the first ever release of information on an innovation project and later announcements as all other announcements during the project.

We find that the difference between the returns to the first announcement of any project and the returns to any later announcement (second, third, or all subsequent) is not significantly different from zero. We also compare the returns to the first announcement in each set of activities with later announcements within the same set of activities and the results are similar. These results belie the expectation that the first announcement is more important. A possible reason might be that later announcements may have equally large (or larger) returns since what they lack in "news" value they make up for by indicating increasing confidence that the project will succeed.

**Returns Relative to Competitors.** Most past studies suggest that when a firm makes an announcement relating to an innovation project, competitors experience negative returns (Akhigbe 2002; Chen, Ho, and Ik 2005; Ferrier and Lee 2002; Zantout and Tsetsekos 1994). We extend the analysis to examine the returns to the focal firm relative to its competitors during the setup, development, and market activities. We create a portfolio of all firms that did not make any announcement on the day the focal firm made an announcement.

Contrary to the findings in the literature, in all three sets of activities, the returns to competitors are not negative (see Table 6, Column 3). These results hold even if we expand the definition of competitors to include all firms across categories in our sample not making the announcement or use wider windows around the day of the announcement (e.g., plus or minus one or two days). However, the returns to the announcing firm are significantly higher than those to competitors (Table 6, Column 5).

## Tests of robustness

We carry out a number of analyses to test the robustness of the results including regression diagnostics, alternative methods to estimate returns, alternate market index, nonparametric tests, and accounting for lack of clean estimation period.

**Regression Diagnostics.** We examine the impact of residuals (outliers) on the outcome and accuracy of the regression results. First, we repeat the regression after trimming the dependent variable by symmetrically capping each tail at the 1% and 2.5% levels. Next, we repeat the regression after removing observations with large residuals (outliers with poten-

Table 6
### Effect of Innovation on Abnormal Returns to Competitors

| | Competitors | | Difference in abnormal returns to competitors and to the announcing firm | | |
|---|---|---|---|---|---|
| Category | Phase | Est. (%) | *t*-value | Diff (%) | *t*-val |
| All | S | .1 | .7 | –.3 | 2.5 |
| | D | .1 | 2.5 | –.7 | 5.1 |
| | M | .1 | 2.3 | –.2 | 2.2 |
| Lighting | S | –.1 | –.6 | –.9 | 2.3 |
| | D | .0 | –.4 | –1.1 | 2.9 |
| | M | .1 | 1.6 | –.7 | 2.4 |
| Monitors | S | .1 | 1.1 | –.4 | 1.3 |
| | D | .1 | .7 | –4.7 | 3.1 |
| | M | .1 | .8 | –.8 | 3.1 |
| Memory | S | .1 | 1.6 | –.3 | .9 |
| | D | .1 | 1.1 | –.4 | 1.7 |
| | M | .0 | –0.1 | –.1 | .8 |
| Data transfer | S | .0 | .3 | –.1 | .6 |
| | D | .2 | 1.2 | –.4 | 1.8 |
| | M | .1 | 1.5 | –.1 | .5 |
| Printers | S | –.2 | –1.5 | –.5 | 1.7 |
| | D | .5 | 3.1 | –.9 | 2.0 |
| | M | .1 | 1.5 | .2 | –1.5 |

Note: S = setup; D = development; M = market.

tially undue influence and/or high leverage on the results) with values of Cook's distance higher than 4/n (Cook 1979). The results are similar to our original results in both cases for all variables except for announcements related to new funds, where the coefficient is still positive but no longer significant.

We also test for presence of autocorrelation of errors using the Durbin-Watson statistic after removing these outliers. The tests fail to reject both null hypotheses of no autocorrelation in the errors against the alternative hypotheses of positive and negative autocorrelation, respectively, for $i^{th}$-order autocorrelation where $0 \leq i \leq 4$.

The White test is significant (Pr > chi-sq = <.0001) and suggests potential heteroscedasticity of residuals. We plot the residuals and contrast them with the fitted values to investigate any patterns of increasing residuals. No such patterns are visible. We also re-estimate the model after removing observations to maintain a constant bound on the variance of residuals; the results are similar.

At both the level of the set of innovation activities and at the level of individual innovation events, multicollinearity is not a problem among the control variables, as indicated by the coefficient variance-decomposition analysis and the condition indices.

**Alternative Methods of Estimating Returns.** We use three other models to estimate "normal" returns in order to verify the robustness of our results—the mean return, market-adjusted return, and market models (McKinlay 1997). First, we use the mean return model (Equation 10), in which the firm is expected to generate the same return that it averaged during a previous estimation period. Next, we use the market-adjusted return model (Equation 11), in which the firm is expected to generate the same return as the rest of the market. Finally, we use the market model, in which the firm is expected to generate the same return as a portfolio of stocks used to represent the overall market (Equation 12).

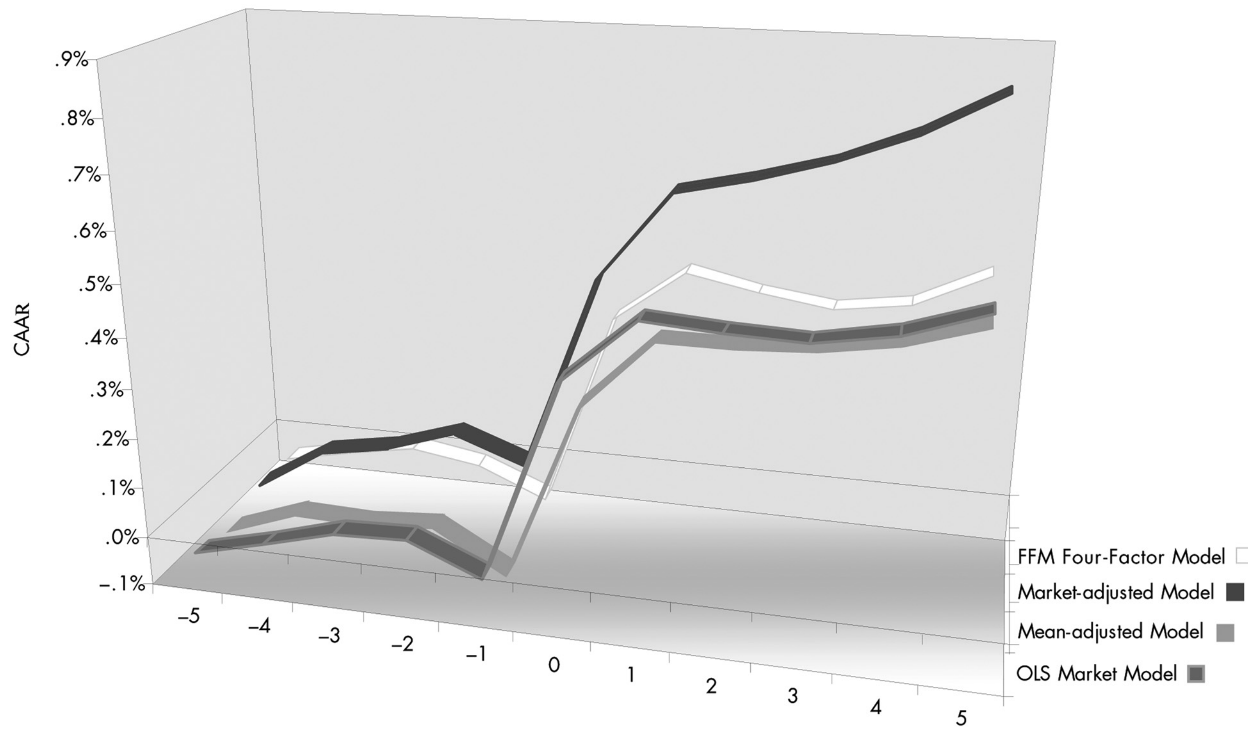
$$R_{it} = R_i + \varepsilon_{it} \quad (10)$$
$$R_{it} = R_{mt} + \varepsilon_{it} \quad (11)$$
$$R_{it} = \alpha_i + R_{mt} + \varepsilon_{it} \quad (12)$$

where $R_{it}$ and $R_{mt}$ are the period $t$ returns on security $i$ and the market portfolio respectively and $\varepsilon_{it}$ is the zero mean disturbance term. The estimation window for all three models is the same as for Equation 1. For each firm $i$ and event date $t$, we have

$$AR^*_{it} = R_{it} - \hat{R}_i \quad (13)$$
$$AR^*_{it} = R_{it} - R_{mt} \quad (14)$$
$$AR^*_{it} = R_{it} - (\hat{\alpha}_i + \hat{\beta}_i R_{mt}) \quad (15)$$

Figure 2

Cumulative Average Abnormal Returns (CAAR) Using OLS Market, Mean-adjusted, Market-adjusted, and FFM Four-Factor Models




Where $AR^*_{it}$, $\hat{R}_i$, $\hat{\alpha}_i$, and $\hat{\beta}_i$ are the abnormal returns, mean firm returns, and parameter estimates of market-adjusted model respectively. The plots of CAAR in Figure 2 using all models—mean, market, and market-adjusted models—demonstrate that the CAAR was not much different with the use of these models. Similarly, there were no significant differences in the reported results for the hypotheses with the use of these alternate models as well.

**Alternative Market Index.** We use the equally weighted market index to estimate the abnormal returns in Equation 1 as per recommendation of Brown and Warner (1980, 1985). We also re-estimate the returns using the value-weighted market index to ensure robustness. The results are not materially different from the ones presented.

**Nonparametric Tests.** We use the Wilcoxon sign rank test to test the null hypothesis that the observed returns are symmetrically distributed around 0 and the proportion of observed sample securities having positive returns is equal to .5. This situation would be true if markets do not respond favorably to positive news of technological innovations. The Wilcoxon sign rank test uses both the sign and the rank information in its test and is therefore more powerful than the simpler binomial sign test. The results reject the null ($p$ = .001) and support our findings that market returns to innovation are positive.

**Accounting for the Lack of a Clean Estimation Period.** An assumption intrinsic to the market-adjusted model is that the estimation period used to estimate market parameters prior to the event is clean; that is, there is no other announcement made by the firm in that period. Since we examine multiple announcements made by the same firm over the entire innovation project, this assumption is violated. We remove the dates of all prior announcements made by the firm from the estimation period (Brown and Warner 1985) and re-estimate the returns, but the results do not change much with this correction.

## Discussion

This section summarizes the findings and discusses implications and limitations.

### Summary of findings

The current research leads to seven major findings:

1. The stock market is highly responsive to innovation. The average total market returns to an innovation project are $643 million, more than 13 times the $49 million that are the returns to an average event in the innovation project.

2. Of the three sets of innovation activities (setup, development, and market), returns to the development activities are consistently the highest both across and within categories.

3. Returns to negative events are higher in absolute value than those to positive events.

4. Returns are consistently higher for small firms than for large firms and for those that focus on a few rather than many technologies.

5. Returns to the announcing firm are substantially greater than those to competitors across all stages.

6. The number of prior announcements and time elapsed since the last announcement have no effect on the market returns to innovation.

7. Returns to the first announcement of an innovation project are not different from returns to later announcements. Similarly, results for older technologies and projects are not different from those for newer ones.

### Implications and contributions to practice

This study has several implications for managers. First, contrary to critics' claim that markets do not respond to innovation due to the markets' short-term orientation, we find that markets respond promptly and substantially to announcements about innovation at all stages of the innovation project. However, when considering the value of innovation, it is inappropriate to limit the analysis to only one or another event in the innovation project. The frequently cited undervaluation of innovation (Hall 1993, 2005; Hall, Mansfield, and Jaffe 1993) may be due not to markets failing to appreciate the full value of innovations immediately but to researchers computing returns to isolated events in an innovation project when they should be computing returns to the total project. Following the approach described in this study, managers can assess the value of any proposed innovation project by comparing the projected costs of the project to the average returns they can expect.

For example, HP invested approximately $45.8 billion in R&D activities from 1989 to 2006. The total returns to all event announcements in the desktop monitor and desktop printer categories were $40.2 billion—an 88% return on investment. Note, however, that investments were for all categories while the returns are for only two categories.

To take another example, AXT develops and markets three product lines of high-performance compound semiconductor substrates: gallium arsenide (GaAs) substrates, indium phosphide (InP) substrates, and single-element substrates. During the period 2000–2003, the firm made various announcements regarding development of new products, allocation of resources to the three product lines (equivalent for our purposes to innovation projects), and expansion of manufacturing facilities. With our approach, we estimate the total returns to innovation activities in the three product lines to be $29.3 million. These returns are about two and a half times their total R&D expenditures (which were $11.9 million) during this period. This represents a 246% return on investment.

Second, the findings on various announcement strategies indicate that a mere increase or decrease in either the frequency or total number of announcements does not lead to an increase or decrease in returns. The median number of prior announcements in our sample is two, and the 90th percentile is nine. Moreover, the first announcement of a project is no more important than later announcements. These results imply that the markets are efficient and that firms cannot game the system by over-announcing or by making multiple announcements of a single event.

Third, the absolute value of a negative announcement is greater than that for a positive announcement. Thus, firms should be cautious not to exaggerate progress in their innovation projects or to resort to vaporware. However, because returns are positive for all positive announcements and significantly different from 0 for all but two of the positive announcements, firms should make it a point to announce these events. Otherwise, they lose the opportunity for increasing market capitalization involved in such announcements. These findings are also consistent with recent findings in marketing literature that suggest markets react positively to new product introductions but discount short-term promotions.

Fourth, returns are highest for development activities. Returns are higher for development activities than for setup activities probably because setup activities involve heavy commitment of expenditures and resources up front, with the payoff uncertain and several years away. Returns are higher for development activities than for market activities probably because development activities reflect the greatest reduction of uncertainty and already capture some of the expected returns from future market capitalizations. Thus, it is important that firms exploit progress in development by fully announcing all development-related events.

Fifth, when announcing innovations, small firms do not seem to suffer any disadvantage relative to large firms. Rather, small firms seem to gain higher returns than large firms, ceteris paribus. A possible reason for this effect is that large firms are intensely researched and covered by the investment community. Thus, good news from small firms is more likely to come as a positive surprise than news from large firms.

## Limitations and future research

This study has several limitations that can be the basis of future research. In all categories, the highest average returns are consistently for announcements related to development activities. However, we could find no strong theory for why this is the case. Second, we limit our analyses to just five categories because of the difficulty collecting a comprehensive set of announcements on all events relating to innovation projects. Third, the data only include firms that are listed on the stock markets. Future research might explore whether the same results hold for unlisted firms. Fourth, the results may be affected by a potential selection bias as firms can be more selective about the type of announcements made during setup and development than during the market stage.

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## Appendix A

### Operating Principles of Sampled Technologies (Adapted from Sood and Tellis 2005)

| Technology | Principle |
|---|---|
| External Lighting | |
| 1 Incandescence | Thin metallic wires that are heated with an electric current generate light. |
| 2 Arc discharge | Electric current between two oppositely charged electrodes in a high-pressure gas chamber creates an arc that generates light. |
| 3 Gas discharge | Electrons excited by passing an electric current through a low-pressure gas chamber emit light. |
| 4 Light-emitting diode (LED) | Under the influence of an electric potential, light is emitted in n-p transition zone. |
| 5 Microwave electrodeless discharge (MED) | Microwaves from an induction coil excite gas inside a bulb and generate light. |
| Display Monitors | |
| 1 Cathode ray tube (CRT) | Electrons fired from an electron gun converge to strike a screen coated with phosphors of different colors, causing an image to form. |
| 2 Liquid crystal display (LCD) | Light passing through the molecular structures of liquid crystals creates an image. |
| 3 Plasma display panel (PDP) | Ultraviolet photons emitted from a gas stored in miniature cells create image. |
| 4 Organic light-emitting diode (OLED) | Positive and negative excitons (holes emitted by anodes and electrons emitted by cathodes) are combined in a polymer dye to create images. |
| Desktop Memory | |
| 1 Magnetic | A frequency-modulated (FM) current passes through the disk drive's magnetic head, thereby generating a magnetic field that magnetizes the particles of the disk's recording surface and permits data to be recorded. |
| 2 Optical | The laser modulation system and changes in reflectivity are used to store and retrieve data. |
| 3 Magneto-optical | The magnetic-field modulation system records data that a laser beam then reads. |
| Computer Printers | |
| 1 Dot matrix | Pins strike against an ink ribbon to print closely spaced dots that form the desired image. |
| 2 Inkjet | Ionized ink is sprayed through micro-nozzles at a sheet of paper to form an image. |
| 3 Laser | Electrostatic charges form an image on a photosensitive surface; the image is then transferred to a sheet of paper using toner ink, and heat is applied to the paper to make the image permanent. |
| 4 Thermal | Sublimation or phase change processes are used to heat ink, and the image forms on paper. |

| Digital Data Transfer | |
|---|---|
| 1 Copper-aluminum | Data travel along wires in the form of electrical energy as analog or digital signals. |
| 2 Fiber optics | Data travel in the form of light pulses through a thin strand of glass using the principles of total internal reflection. |
| 3 Wireless | Data are encoded in the form of a sine wave and transmitted via radio waves using a transmitter-receiver combination. |

## Appendix B

### Examples of Positive and Negative Announcements

**Joint Ventures**
Positive: Cree Research and Philips sign joint agreement; new laser diodes will increase optical storage capacity; ARPA provides $4 million funding.

Negative: Hitachi, GE dissolve lighting joint venture.

**New Funds**
Positive: Intel to invest $100 million in Hitachi, Ltd.'s joint venture with Elpida Memory Inc.-DJ.

Negative: Storage Technology loses loan.

**New Prototypes**
Positive: IBM says it set record for bits of data on disk.

Negative: Gentex delays new LED technology.

**New Patents**
Positive: Universal Display Corp. announces issuance of the fourteenth patent in the organic light emitter project.

Negative: Seagate files patent infringement lawsuit against Storage Computer Corp.

**Preannouncements**
Positive: Sony Corp. of Japan said on Tuesday it will launch a home-use optical-type videodisc player, "Laser Max," on April 21.

Negative: Sony to delay mass production of digital audio tape (DAT) heads.

**Product Launch**
Positive: Sony expands 5.25-inch magneto-optical library line to include permanent WORM configurations.

Negative: IBM to recall up to 117,000 monitors over fire concern.

**Quality Awards**
Positive: EPA names Lexmark International "Energy Star Printer Partner of the Year."

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